Research on the bending and tensile mechanical properties of ceramic yarns

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ABSTRACT – REZUMAT

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Ceramic yarns play an important role in the aerospace sector, aviation, military, shipbuilding and nuclear industry, they have some advantages of high-temperature resistance, high specific strength and high specific modulus. However, almost no one studies the bending properties of ceramic yarns. To explore the influence of the degree of bending of ceramic yarn on its mechanical properties, three kinds of ceramic yarns (silicon carbide, silicon nitride and alumina) were knotting, bending and checking tensile tests. The retention rate of silicon nitride yarn after bending, checking and knotting tensile tests was 81.9%, 3.39% and 0.17%. The retention rate of silicon carbide yarn after bending, checking and knotting tensile tests was 95.1%, 4.88% and 0.09%, respectively. After bending, checking and knotting tensile tests, the fracture strength retention rate of alumina yarn was 91.8%, 0.39% and 0.04%. It was proved that the retention rate of breaking strength of ceramic yarn decreases seriously under different forms of bending. As a result, ceramic yarns should not be used under bending conditions.

Keywords: *ceramic yarn, kinking property, knotting property, entanglement property, retention rate of fracture strength*

Studiu privind proprietățile mecanice de rezistenţă la încovoiere și tracțiune ale firelor ceramice

Firele ceramice joacă un rol important în sectorul aerospațial, aviație, sectorul militar, construcții navale și industria nucleară, având unele avantaje de rezistență la temperaturi ridicate, rezistență specifică ridicată și modul specific ridicat. Cu toate acestea, aproape nimeni nu studiază proprietățile de rezistenţă la încovoiere a firelor ceramice. Pentru a explora influența gradului de încovoiere a firelor ceramice asupra proprietăților sale mecanice, trei tipuri de fire ceramice (carbură de siliciu, nitrură de siliciu și alumină) au fost supuse la încercări de rezistenţă la înnodare, încovoiere și verificare la tracțiune. Rata de retenție a firelor de nitrură de siliciu după încercările de rezistenţă la încovoiere, verificare și înnodare la tracţiune a fost de 81,9%, 3,39% și 0,17%. Rata de retenție a firelor de carbură de siliciu după încercările de rezistenţă la încovoiere, verificare și înnodare la tracţiune a fost de 95,1%, 4,88% și, respectiv, 0,09%. După încercările de rezistenţă la încovoiere, verificare și înnodare la tracţiune, rata de retenţie a rezistenței la rupere a firului de alumină a fost de 91,8%, 0,39% și 0,04%. S-a dovedit că rata de retenție a rezistenței la rupere a firelor ceramice scade foarte mult sub diferite forme de încovoiere. Prin urmare, firele ceramice nu trebuie folosite în condiții de încovoiere.

Cuvinte-cheie*: fire ceramice, proprietate de rezistenţă la încovoiere, proprietate de rezistenţă la înnodare, proprietate de rezistenţă la încurcare, rata de retenţie a rezistenței la rupere*

INTRODUCTION

The rapid development of aerospace, aviation, military, shipbuilding and the nuclear industry has promoted the research and development of continuous ceramic yarns, and some new continuous ceramic yarns such as Si_3N_4 yarn, SiC yarn and Al_2O_3 yarn have appeared in public view [1–3], which have excellent properties such as high-temperature resistance, high elastic modulus, high strength, high rigidity, light specific gravity and corrosion resistance [3–6]. In addition, the ceramic yarn can overcome the sensitivity of ceramic to crack and thermal shock effectively, especially since it has a non-failure fracture mode which is different from ordinary ceramics [7].

At present, the United States, Europe, Japan and other countries have invested a lot of energy in the research and production of ceramic yarns. A series of studies on the mechanical and thermal properties of ceramic yarns show that ceramic yarns will usher in a brand-new era. The mechanical properties of ceramic yarns include many aspects (tensile, compression, bending, torsion, impact, alternating stress), but there is a lack of comparative analysis of various experimental data [8]. However, ceramic yarns are mostly used in various products as soft braided bodies, which are in bending, folding, twisting and other states. Studying the mechanical properties of ceramic yarns in a bending state can more effectively reflect the properties of composite materials [9–11].

In this paper, the tensile test, bending test, knotting test and beading test of ceramic yarns are studied at first, and then the strength retention rate of ceramic yarns is observed to judge the strength loss of yarns with different bending degrees. Secondly, to further explore the influence of different radius of curvature on the strength of Al_2O_3 yarn, alumina yarn in ceramic yarn was selected to explore the influence of bending of Al_2O_3 yarn under different radius of curvature on mechanical properties. Finally, through data processing and statistical analysis, the basic mechanical properties of continuous ceramic yarn such as load, strength, stress, modulus and tensile strain are comprehensively evaluated [11–15].

BENDING FRACTURE MECHANISM OF CERAMIC YARNS

Bending stiffness of yarn

The bending stiffness of yarn determines its ability to resist bending deformation. The bending stiffness is large, the yarn is not easy to bend and deform, and the fabric is stiff. According to material mechanics, the bending stiffness of yarn is:

$$R_B = EI \quad (1)$$

where R_B is the bending stiffness of yarn (cN·cm^2); E is the elastic modulus of yarn (cN/cm^2); I is the sectional inertia moment of yarn (cm^4), a moment of inertia of circular section axis: $I_0 = \pi r^4/4$. However, the cross-section shape of the yarn is generally non-circular. To simplify the calculation, the sectional inertia moment of the yarn is usually calculated by equation 2:

$$I_f = \frac{\pi}{4}\eta_f \cdot \bar{r}^4 \quad (2)$$

Where I_f is the sectional inertia moment of yarn (cm^4); $\bar{r}$ is the equivalent radius when the yarn section is converted into a circle according to the equal area (cm); η_f is the section shape coefficient and the actual section axis inertia moment of the yarn I_f and the moment of inertia when converting to a regular circle I_0 ratio. Therefore, the actual bending stiffness of the yarn is:

$$R_f = \frac{\pi}{4}\eta_f \cdot E \cdot \bar{r}^4 = EI_0 \cdot \eta_f \quad (3)$$

Assume that the yarn density is γ (g/cm^3), and the linear density is N_{dt}, from the conversion formula of yarn linear density and radius:

$$\bar{r}^2 = (N \cdot d_t / \pi\gamma) \times 10^{-4} \quad (4)$$

$$R_f = \frac{1}{4\pi}\eta_f \cdot E \cdot (N_{dt}/\gamma^2) \quad (5)$$

The bending stiffness is proportional to the square of the linear density when the yarn thickness is different. To compare yarns with each other, the unit thickness is usually adopted (tex) yarn bending stiffness $R_{fr.}$ Therefore:

$$R_{fr} = \frac{1}{4\pi}\eta_f \cdot E \cdot (Nt/\gamma^2) \times 10^{-10}\ (\text{cN}\cdot\text{cm}^2/\text{tex}) \quad (6)$$

When a specific modulus is adopted (cN/tex), the formula is converted to:

$$R_{fr} = \frac{1}{4\pi}\eta_f \times (E \cdot \frac{Nt}{\gamma^2}) \times 10^{-5}\ (\text{cN}\cdot\text{cm}^4/\text{tex}^2) \quad (7)$$

Bending failure of yarn

When the yarn is bent, the deformation on the bending layer is different, as shown in figure 1, *a*. The neutral surface is stretched above *OO′*; the neutral plane below *OO′* is compressed. The greater the bending curvature, that is, the smaller the radius of curvature *r*, the greater the deformation difference of each layer. I_f the radius of curvature is too small, the outer layer will crack and the inner layer will extrude until it breaks, as shown in figure 1, *b*.

When the yarn diameter is *d*, the strain of the outermost layer ε for:

$$\varepsilon = \frac{\overline{34} - \overline{12}}{\overline{12}} = \frac{d}{2r} \quad (8)$$

Where $\overline{34} = \left(r + \frac{d}{2}\right)\gamma$; $\overline{12} = r\gamma$, with the decrease of the curvature radius *r* of the yarn bending deformation, the elongation of the outer layer of the yarn increases. When ε to the tensile breaking strain of the yarn ε_b, the outermost layer starts to fracture, and then is

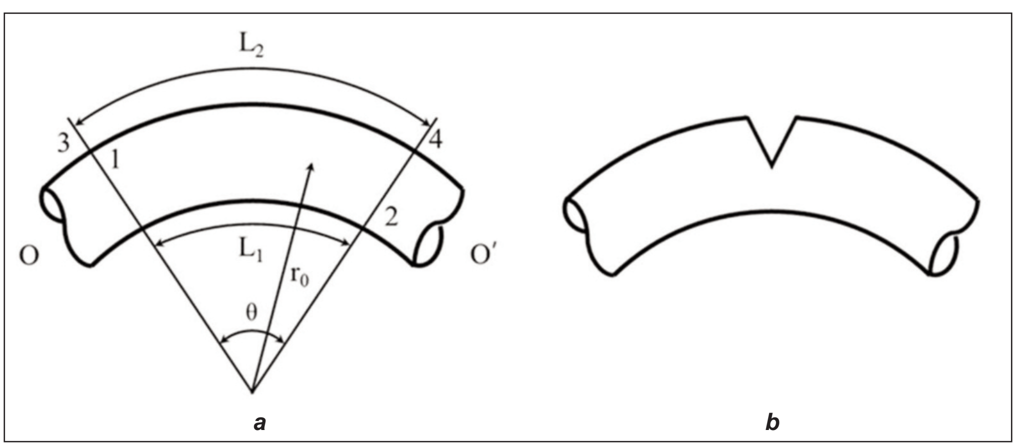

Fig. 1. Deformation and damage of yarn during bending

fractured by crack propagation. Therefore, the minimum curvature radius r of yarn surface fracture is:

$$r \geq \frac{d}{2\varepsilon_b} \quad (9)$$

The thinner the yarn, and d is smaller, the tensile breaking strain ε_b the bigger the harder it is to break. Glass, metal, carbon, ceramics and other rigid and brittle yarns ε_b less than 1%, but cotton, wool, hemp and silk are common ε_b is greater than 10%, so common ceramic yarn and its stiffness.

MATERIAL AND METHODS

Materials and instruments

Materials: Si_3N_4 yarn (201 tex, Shandong Dongheng Co, Ltd., China), SiC yarn (202 tex, Shandong Dongheng Co, Ltd., China), Al_2O_3 yarn (198 tex, Shandong Dongheng Co, Ltd., China) (figure 2).

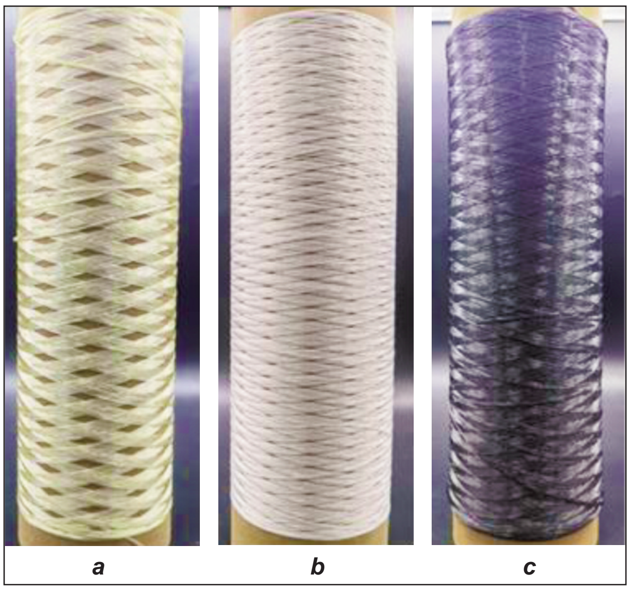

Fig. 2. Studied yarns: *a* – Si_3N_4 yarn; *b* – Al_2O_3 yarn; *c* – SiC yarn

Instruments: Electronic strength universal testing machine (INSTRON 5967, USA), Precision balance (SaiDolis, Germany), Scanning electron microscope (S-4800, Japan).

According to the national standard IOS/T 7690.1, take a certain length of yarn, weigh it with a precision balance (accuracy 0.0001 g), and calculate the linear density of the yarn:

$$N_t = \frac{G_k}{L} \times 1000 \quad (10)$$

where N_t is the linear density of yarn (unit: tex); G_k is yarn weight (unit: g); L is the yarn length (unit: m).

Yarn bending tensile strength test

For the following four tensile tests, the experimental conditions are as follows: clamping distance of 100 mm, stretching speed of 20 mm/min, pre-tension of 0.1–0.2 cN, room temperature of 17°C and relative humidity of 60%.

Testing of tensile properties of ceramic yarns

Sample preparation: cut out 5 yarns of Si_3N_4, SiC and Al_2O_3 each with a length of 150 mm, and fix the two ends of the yarn sample with cardboard to ensure that the yarn does not slip off. When both ends of the sample are clamped, make sure that the test distance of the middle part of the sample is 100 mm, as shown in figure 3, *a*.

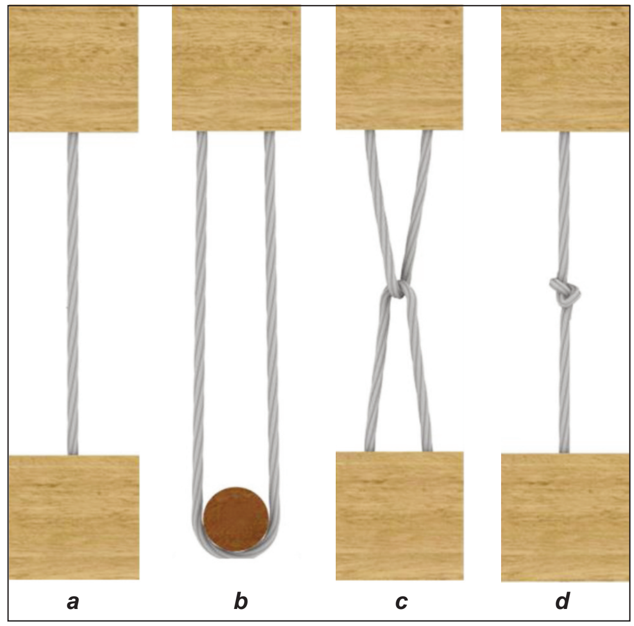

Fig. 3. Graphical representation of: *a* – tensile simulation diagram of ceramic yarn; *b* – simulation diagram of ceramic yarn bending; *c* – simulation diagram of ceramic yarn checking; *d* – simulation diagram of ceramic yarn knotting

Testing of bending tensile properties of ceramic yarn

Sample preparation: use a 3D printer to make a cylindrical mould with a radius of 10 mm and a height of 8 mm, as shown in the third mould in figure 3, *b*; cut out five yarns of Si_3N_4, SiC and Al_2O_3, each 300 mm long, make the yarns into a circle, and use lapels to clamp one end of the yarns together and stick them together, which is conducive to clamping the pattern. When the collar is turned on the end of the sample, the measured sample length is 100 mm, as shown in figure 3, *b*.

Testing of Checking tensile properties of ceramic yarn

Preparation: cut five yarns of Si_3N_4, SiC and Al_2O_3, each of which is 150 mm long, and hook them. Both ends of the yarn are fixed with cardboard to ensure that the yarn does not slip. When both ends of the sample are clamped, make sure that the test distance of the middle part of the sample is 100 mm, as shown in figure 3, *c*.

Testing of knotting tensile properties of ceramic yarn

Sample preparation: cut five yarns of Si_3N_4, SiC and Al_2O_3 each with a length of 150 mm, tie them, and fix the two ends of the yarn sample with cardboard to ensure that the yarn does not slip. When the two ends of the sample are clamped, the test distance of the middle part of the sample is 100 mm, as shown in figure 3, *d*.

To further analyse the relationship between stretching and bending of ceramic yarn, the formula is used to calculate the breaking strength retention ratio W_1 (%) after bending, and the formula is used to calculate the breaking strain retention ratio W_2 (%) after bending:

$$W_1 = \frac{P_f}{2 \times P_y} \times 100\% \quad (11)$$

Where P_f for yarn strength after bending (unit: N), P_y for yarn stretching strength (unit: N).

$$W_2 = \frac{Q_f}{2 \times Q_y} \times 100\% \quad (11)$$

Where Q_f for yarn strength after bending, Q_y for yarn stretching strength.

Yarn fineness tensile strength test

Experimental conditions: room temperature of 17 °C and relative humidity of 60%.

In the experiment above, only the effect of bending on the strength of ceramic yarns(Si_3N_4 yarn, SiC yarn, Al_2O_3 yarn) was explored, did not explore whether the fineness of ceramic yarn affects strength, three different ceramic yarns are stranded, three and five pieces of three ceramic yarns were paralleled, they tested their tensile breaking strength. After parallel treatment of 3 and 5 pieces of three ceramic yarns, test their tensile breaking strength. The sample preparation is shown in figure 4.

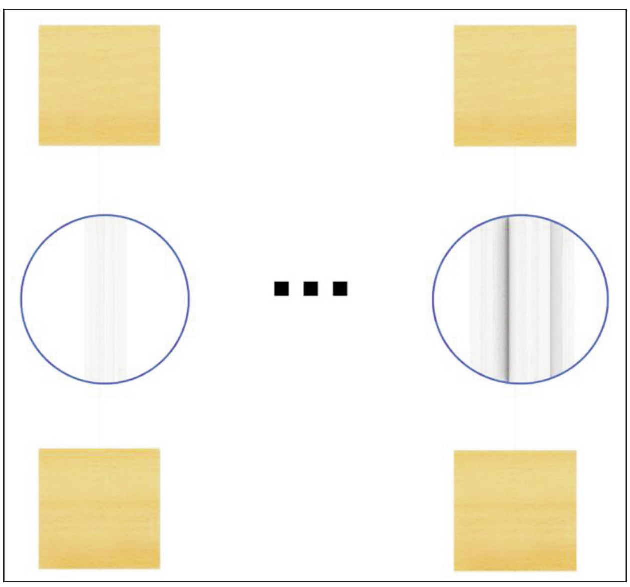

Fig. 4. Schematic diagram of ceramic yarn strand simulation

Yarn surface topography test

Experimental conditions: room temperature of 17 °C and relative humidity of 60%.

Sample preparation: in the experiment, the ceramic yarns before and after breaking were shear treated, and the samples were made from the shear yarns, which were pasted on the sample table with conductive adhesive and sprayed with gold. Scanning electron microscopy was used to observe the surface morphology characteristics of the three ceramic yarns (Si_3N_4 yarn, SiC yarn, Al_2O_3 yarn) and the microstructure of the fracture incision before and after stretching.

RESULTS AND ANALYSIS

Mechanical properties of ceramic yarn

Testing of tensile properties of ceramic yarns

To explore the mechanical properties of different yarns after stretching, this section tests the mechanical properties of three kinds of ceramic yarns under the same curvature radius.

Table 1

SPECIFICATION PARAMETERS AND TENSILE PROPERTY OF THE CERAMICS YARNS

Category	Fineness (tex)	Stain (%)	Strength (N)
SiC	200	1.12	122.38
Si_3N_4	200	0.88	44.89
Al_2O_3	200	0.96	73.01

As shown in table 1, the linear density of Si_3N_4, SiC and Al_2O_3 is the same, Judging from the number of strands, all three kinds of ceramic yarns are composed of single yarn; the tensile breaking strength of SiC yarn is 122.38 N, which is the highest among all yarns, about 1.5 times that of Al_2O_3 yarn and about 3 times that of Si_3N_4 yarn.

As shown in figure 5, *a*, three different bending methods, the bending angle increases sequentially, and the strength decreases sequentially due to the high stiffness of the ceramic yarn, the peak of the image is the breakage of the yarn, which is also the maximum strength of the yarn. In addition, as can be seen from figure 6, the fracture mode of ceramic filaments is not brittle fracture like most filaments, but explosive fracture and the fracture opening is shower-shaped.

Testing of bending tensile properties of ceramic yarn

To explore the mechanical properties of different yarns after bending, this section tests the mechanical properties of three kinds of ceramic yarns under the same curvature radius, as shown in table 2.

After the bending test, the retention rate of mechanical properties is one of the important indexes to

Table 2

TENSILE PROPERTY OF THE CERAMICS YARNS AFTER BENDING

Category	Strength (N)	Stain (%)	Retention rate (%)
SiC	234.2	1.35	95.7
Si_3N_4	85.7	0.77	95.5
Al_2O_3	134.4	1.12	92.1

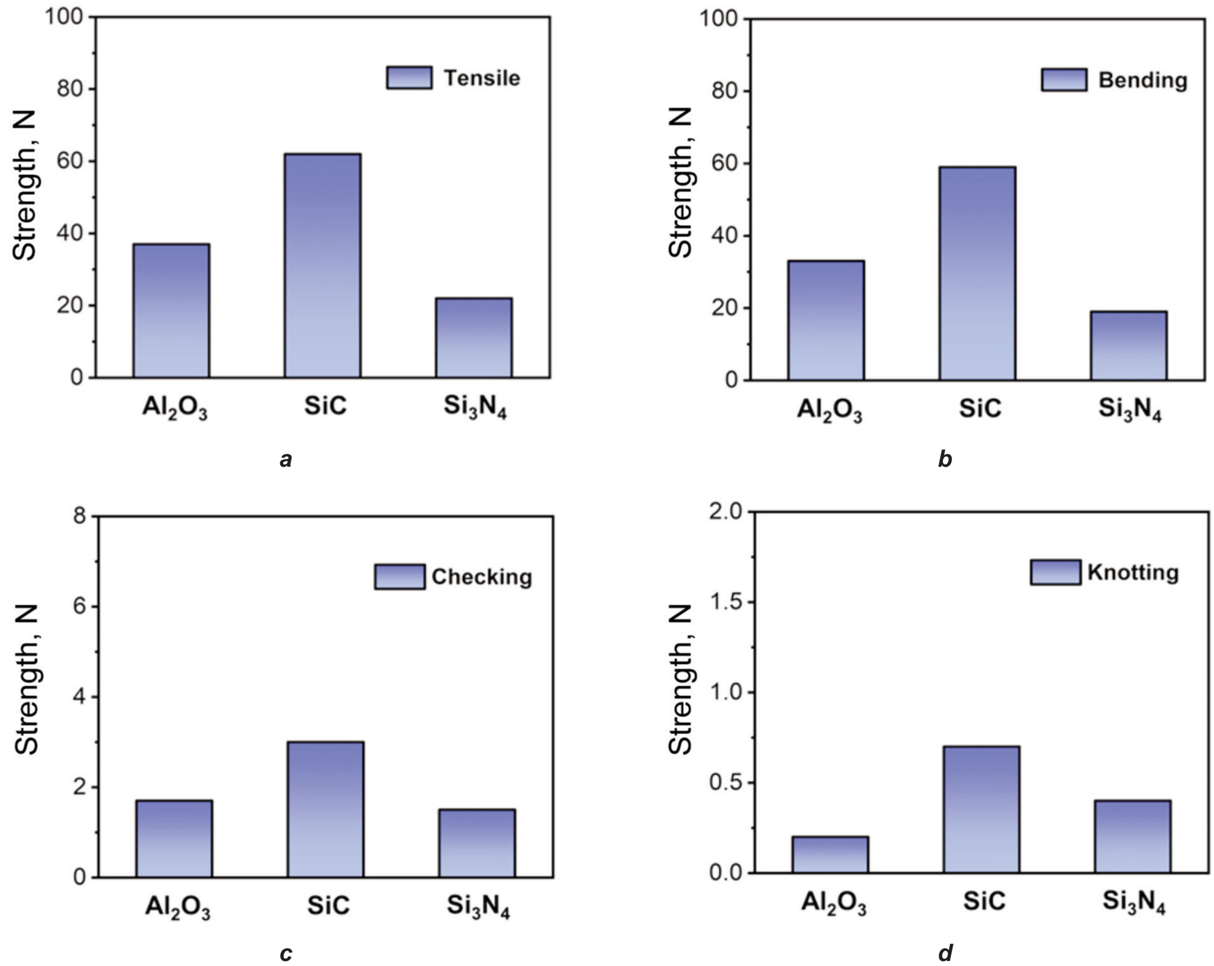

Fig. 5. Graph of: *a* – tensile strength strain curve of ceramic yarn; *b* – bending strength strain curve of ceramic yarn; *c* – checking strength strain curve of ceramic yarn; *d* – knotting strength strain curve of ceramic yarn

valuate the bending resistance of ceramic yarns. To explore the bending resistance of ceramic yarn, a rubber mould with a radius of 10 mm and a height of 8 mm is made, and the ceramic yarn is wound on the mould, and then the tensile test is carried out on the Instron electronic universal testing machine. Table 2 for specific data on bending and tensile mechanical properties of ceramic yarns. It can be seen that the fracture strengths of SiC and Si_3N_4 after bending are 234.2 N and 85.7 N. Respectively, the breaking strength and strain of Al_2O_3 after bending are 134.40 N and 1.12%. Therefore, the breaking strength retention ratio W_1 and breaking strain retention ratio W_2 can be calculated.

After bending the tensile properties of the ceramic yarns are shown in table 2. After bending, the breaking strength and breaking strain of the three kinds of ceramic yarns show a downward trend. It can be seen that the breaking strength retention rate of SiC and Si_3N_4 yarns is between 95% and 96%, and the yarn strength is partially lost. The breaking strength retention rate of alumina yarn is about 92%, and the breaking strength retention rate of Al_2O_3 yarn is the lowest. It can be seen that the breaking strength loss of Al_2O_3 yarn after bending treatment is the largest.

Testing of checking tensile properties of ceramic yarn

As shown in table 3, to explore the mechanical properties of different yarns in checking, this section tests the mechanical properties of three kinds of ceramic yarns under the same curvature radius.

Table 3

TENSILE PROPERTY OF THE CERAMICS YARNS AFTER BENDING

Category	Strength (N)	Stain (%)	Retention rate (%)
5.97	1.12	4.92	95.7
1.68	0.88	7.53	95.5
1.56	1.96	4.37	92.1

After the ceramic yarn is crosslinked, the breaking strength and breaking strength of the yarn decrease obviously. The breaking strength of SiC is 5.97 N, and the breaking strength retention rate is 4.92%, which is the highest among the three yarns. The fracture strength of Si_3N_4 is 1.68 N, and the fracture retention rate is 7.53%. The breaking strength of Al_2O_3 is 1.56 N, and the breaking retention rate is 4.37%. As can be seen from figure 6, *a–c*, in the process of series-parallel drawing, the yarn also explosively breaks, and it also has some basic characteristics such as different breaking times.

Testing of knotting tensile properties of ceramic yarn

To explore the mechanical properties of different knotted yarns, this section tests the mechanical properties of three kinds of ceramic yarns under the same curvature radius, as shown in table 4.

Table 4

TENSILE PROPERTY OF THE CERAMICS YARNS AFTER KNOTTING

Category	Strength (N)	Stain (%)	Retention rate (%)
SiC	0.12	4.34	1.06
Si_3N_4	0.08	6.99	2.01
Al_2O_3	0.03	2.22	0.61

After the ceramic yarn is knotted, the breaking strength and breaking strength of the yarn decrease more obviously. The fracture strength of SiC is 0.12 N, and the retention rate of fracture strength is 1.06%. The breaking strength of Si_3N_4 is 0.08 N, and the breaking retention rate is 2.01%, which is the highest among the three yarns. The breaking strength of Al_2O_3 is 0.03 N, and the breaking retention rate is 0.61%.

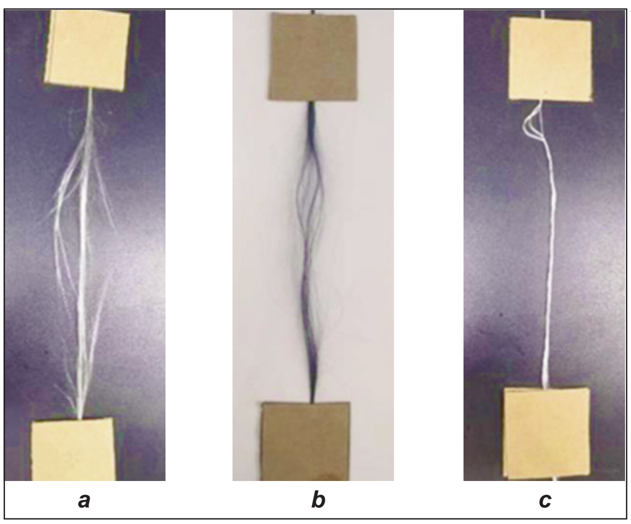

Fig. 6. Graphical representation of: *a* – fracture morphology of Si_3N_4 yarn; *b* – fracture morphology of SiC yarn; *c* – fracture morphology of Al_2O_3 yarn

Mechanical properties of ceramic yarn fineness

As the fineness of the ceramic yarn increases, the loss of tensile strength becomes greater after bending, as shown in figure 7. The reason for the analysis is that the ceramic yarn is a leather core structure [16–22], from formula 1, it can be seen that as the fineness becomes larger, its stiffness also increases, so it is not easy to bend and deform, from equations 3 and 6, it can also be seen that the linear density and stiffness of the yarn are directly proportional, the linear density increases, the greater the stiffness, so the strength loss is greater when bending; from formulas 8 and 9, it can be seen that the smaller the radius of the yarn, the smaller the number of broken fibers in the outer layer, and with the larger the radius, the number of broken fibers increases, so the strength loss is large.

Surface microtopography of ceramic yarn

SEM photos of three kinds of ceramic yarns (SiC, Si_3N_4, Al_2O_3) are displayed, as shown in figure 8. Figure 8, *a–c* is the schematic diagram of the morphological characteristics of SiC, Si_3N_4 and Al_2O_3 yarns in turn. It can be seen that the surface of the three ceramic yarns is very clean, there are almost no particles on the surface of the fibres, and the fibre thickness is relatively uniform. This is because the composition of the yarn is micron or submicron particles, which will not cause obvious agglomeration.

The fracture notch image of single SiC, Si_3N_4 and Al_2O_3 fibres under 6000 times electron microscope, as shown in figure 8, *g–i*. It can be seen that the fracture notch section presents an irregular fracture, in which the fracture notch section of Si_3N_4 fibre is more regular and neat than that of the other two fibres. However, a little debris can be seen at the fracture section of Al_2O_3 and Si_3N_4 fibres, which is sufficient to show that its agglomeration effect is not as strong as that of SiC fibre, which also verifies the conclusion in figure 6, *a, b*. The tensile and bending breaking strength of SiC yarn is higher than that of Al_2O_3 and Si_3N_4 yarn.

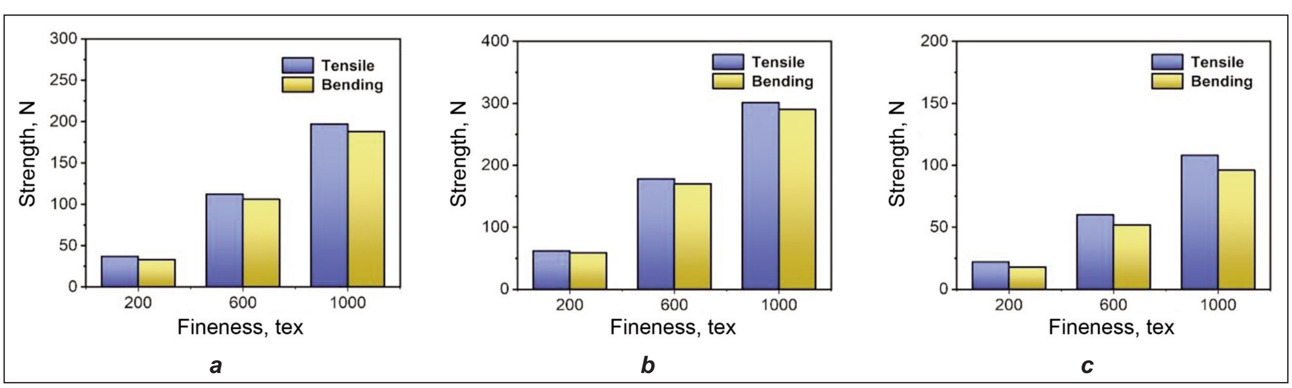

Fig. 7. Graphs of: *a* – fracture morphology of Al_2O_3 yarn; *b* – fracture morphology of SiC yarn; *c* – fracture morphology of Si_3N4 yarn

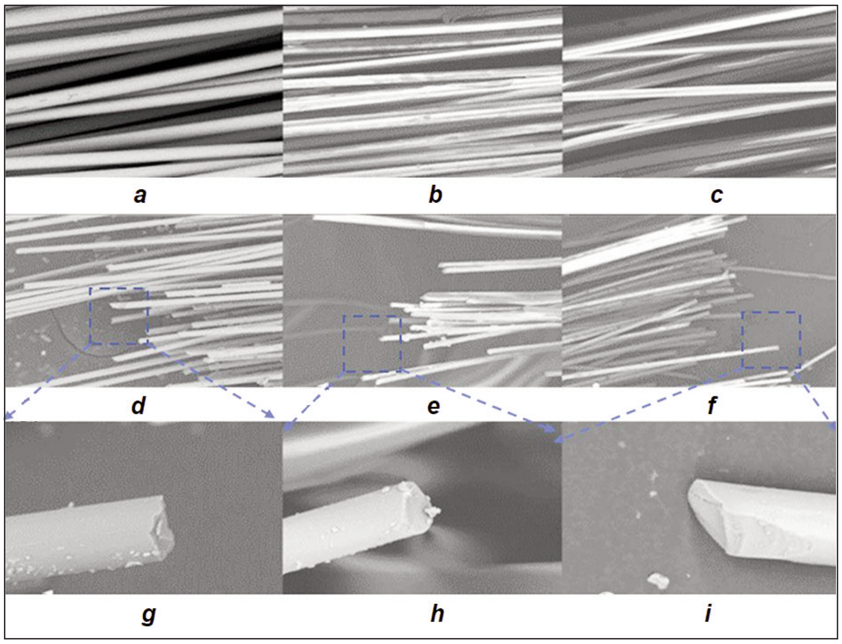

Fig. 8. Graphical representation of: *a–c* – morphological characteristics of ceramic yarn; *d–f* – fracture notch morphology of ceramic yarn; *g–i* – fracture notch of ceramic fibre

The schematic diagram of the morphological characteristics of the fracture notch of SiC, Si_3N_4 and Al_2O_3 yarns in turn, as shown in figure 8, *d–f*. It can be seen that the fibres in the three kinds of ceramic yarns are distributed in parallel, and the fibres at the fracture notch are uneven, which can verify the different fracture timing of the ceramic yarn in figure 8, *a–c*. The yarn is a parallel bundle of fibres, when bending and breaking, the outer fibre breaks first, as shown in figure 1, and according to the analysis of formula 1–7, it can be seen that the greater the rigidity of the yarn, the faster the external fibre breaks, and after the internal fibre is completely broken, it will lead to different yarn fracture lengths and unevenness, as shown in figure 8, *d–f*.

Ceramic yarn sizing treatment

To solve the problem of strong loss of ceramic yarn, it can be seen from consulting the literature method that there are currently three methods on the market to change the strength of ceramic yarn:

- Passivate the ceramic fibre structure by high temperatures, such as increasing the density and graphitization degree of the surface layer, thereby increasing the difficulty of oxygen diffusion to the inside, achieving the purpose of oxidation resistance, and increasing its fracture strength [19].
- Through physical or chemical methods, prepare a high-temperature resistant coating on the surface of the fibre to block the direct contact between oxygen and the fibre, thereby reducing the weight loss rate of ceramic fibre at high temperatures and increasing the strength of the yarn [20].
- Through the method of surface coating, will not only reduce the loss of fibre mechanical properties but also improve the interface adhesion with the substrate material. We use a surface coating method to optimise the strength of the ceramic yarn [21].

Adding 4 g of melamine to 200 ml of deionized water and stirring at 85°C to dissolve; weighing 2 g boric acid dissolved in 50 ml of deionized water and adding melamine aqueous solution; the mixed solution was reacted at 85°C for 1 h, and the h-BN precursor was obtained by rotary evaporation at 95°C. Weighing 2.5 g ammonium molybdate and 3 g PVP-K30 dissolved in 30, in 20 ml of deionised water, 2.5 ml of 1 mol/l Hcl was added after mixing the two solutions well, and irradiated under 365 nm ultraviolet light for 30 minutes, and the prepared 2 g h-BN precursor was added to it, and coated after ultrasound Layer solution [22, 23]. To obtain the coating solution, the ceramic yarn is sized by the method shown in figure 9, *a*, and after cooling, the bending and tensile strength test is carried out, and the test results are

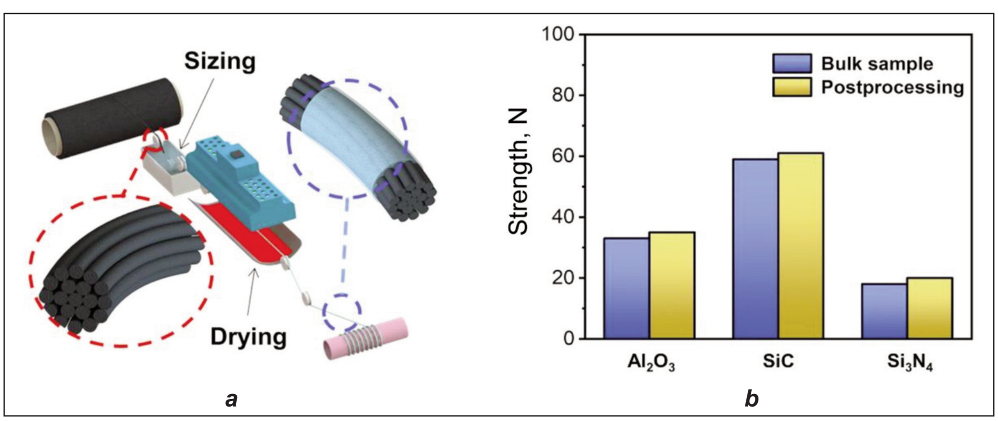

Fig. 9. Graphical representation of: *a* – ceramic yarn sizing simulation diagram; *b* – ceramic yarn bending and stretching strength diagram after sizing

shown in figure 9, *b*. After sizing, ceramic yarns bend strongly, which is significantly better than unsizing ceramic yarns.

CONCLUSIONS

This work mainly explores the influence of bending degree on the tensile breaking strength of ceramic yarn. The tensile test of SiC, Si_3N_4 and Al_2O_3 ceramic yarns with different bending degrees is carried out by using the INSTRON 5967 yarn strength tester. The following conclusions are obtained:

- The strength of SiC yarn is higher than that of Al_2O_3 yarn and Si_3N_4 yarn in turn, and Si_3N_4 yarn is the weakest when the three kinds of ceramic yarns are not bent and then tested for tensile fracture. In addition, the fineness of the yarn affects the bending strength of the ceramic yarn, and the greater the fineness, the greater the strength loss rate when bending the application.
- Fracture test shall be conducted for three kinds of ceramic yarns with different bending degrees. It was found that the tensile strength of SiC yarn decreased by 4.3%, Si_3N_4 yarn by 4.2%, and Al_2O_3 yarn by 7.9% under bending. In the colluded state, the SiC yarn decreased by 95.1%, silicon nitride decreased by 96.6%, and Al_2O_3 yarn decreased by 99.6%. In the knotted state, the Si_3N_4 yarn decreases by 99.9%, the Si_3N_4 yarn decreases by 99.8%, and the Al_2O_3 yarn decreases by 99.8%.

To sum up, it can be seen that the inherent tensile breaking strength of the ceramic yarn is high, but after bending treatment, that is, the smaller the curvature radius of the yarn is, the higher the loss rate of tensile breaking strength is. Therefore, ceramic yarn is not easy to apply in bending, so how to improve the transverse shear force of ceramic yarn is also a challenge in the field of textile mechanics.

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